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AN INVESTIGATION OF THE CHARACTERISTICS OF STEEL DIAPHRAGMS FOR AUTOMATIC FUEL-INJECTION VALVES

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AN INVESTIGATION OF THE CHARACTERISTICS OF STEEL DIAPHRAGMS FOR AUTOMATIC FUEL INJECTION VALVES.

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Summary

This research on steel diaphragms was undertaken at the Langley Memorial Aeronautical Laboratory, as a part of a general investigation of fuel injection engines for aircraft. The work determined the load-deflection, load-deformation and hysteresis characteristics for single diaphragms having thicknesses from 0.002 inch to 0.012 inch, and for similar diaphragms tested in multiple having total thicknesses from 0.012 inch to 0.180 inch. The elastic limit loads and deflections, and rupture points of single diaphragms were also determined. Some work was done on diaphragms having central orifices in order to determine the effect of orifice diameter upon the load-deflection characteristics.

All diaphragms were firmly clamped at their edges in an injection valve and loaded by hydraulic pressure. The deflections were measured with a dial test indicator. The diameters of the unsupported area and of the whole diaphragm were 0.4 inch and 0.5 inch, respectively.

The results of these tests show that the deflections of single diaphragms vary with the square root of the unit load multiplied by a constant and inversely as a variable function of the diaphragm thickness which, for very small deflections, is the cube of the thickness but which decreases rapidly to approximately the 0.8 power of the thickness at a deflection of 0.010 inch. The elastic limit deflections were found to vary from approximately 0.016 inch to 0.011 inch for diaphragm thicknesses ranging from 0.002 inch to 0.012 inch. The rupture point deflections ranged from 0.027 inch to 0.038 inch.

The load capacities of diaphragms used in multiple increased almost directly with multiple thickness and for equal multiple thicknesses, with a variable function of the individual diaphragm thickness. The load capacities of diaphragms with orifices increased rapidly with increase in the orifice size.

The hysteresis of single and multiple diaphragms was found to increase in general with diaphragm thickness. The hysteresis per diaphragm remained practically constant with variable multiple thickness for thin diaphragms but for thick ones the hysteresis increased rapidly with multiple thickness.

Deformation occurred first at the clamped edge and second over the whole unsupported portion of the diaphragm. These deformations took place at practically the same deflections for the thin diaphragms but for the thick ones the deformation at

the clamped edge took place much earlier.

The formulas usually given for the deflections of circular plates were found to be inapplicable to the range of test conditions of this research.

It is concluded that steel diaphragms used in multiple have capacities and characteristics that make them suitable for use in automatic fuel-injection valves.

Introduction

In order to attain efficient combustion in a high-speed fuel-injection engine, each part of the fuel system must not only be carefully designed but it is actually necessary that each part be separately investigated. The injection valve plays a very important part in the control and utilization of the pressures developed by the pump and in the atomization and distribution of the fuel in the engine cylinder. It is necessary to investigate therefore, if maximum efficiency is to be obtained, not only the performance of an injection valve in engine service but also the characteristics and limitations of its various parts.

The results of an investigation on the discharge characteristics of small round orifices suitable for use in fuel-injection valves have been published in N.A.C.A. Technical Report No. 224 (Reference 1). While the general subject of diaphragms has received considerable valuable analysis and dis-

cussion in a report by M. D. Hersey (Reference 2) and a paper entitled "On the Depression of the Centre of a Thin Circular Disc of Steel Under Normal Pressure," by Stanley Smith, has been published by the Royal Society of Canada, no data has been published as far as is known on small diameter steel diaphragms suitable for use as the flexible member in automatic fuel-injection valves. The fact that diaphragms have frequencies higher than those of other forms of springs, that their masses and inertias are very small, that their accelerations are unrestricted by external friction and that they eliminate the necessity for the use of helical springs and lapped valve stems and guides with their consequent wear and leakage, makes their use desirable in fuel-injection valves for high-speed engines.

The work presented in this report refers to steel diaphragms of various kinds and thicknesses suitable for use in automatic fuel-injection valves. The diaphragms differed from each other by having central orifices of various diameters, having no orifices, and in the thickness and number of similar diaphragms laid one upon the other. Load-deflection, load-deformation, and hysteresis characteristics; elastic limit loads and deflections; and rupture points were determined for single diaphragms without orifices. Load-deflection and hysteresis characteristics were determined for multiple diaphragms without orifices. The effect of orifice diameter upon

the load-deflection characteristics of diaphragms with orifices was determined. The thickness of the individual diaphragms ranged from 0.002 inch to 0.012 inch. The thickness of diaphragms tested in multiple ranged up to 0.180 inch. The diameters of the unsupported area and of the whole diaphragm were 0.4 and 0.5 inch, respectively. Static hydraulic pressures up to 16,000 lb. per sq.in. were applied and deflections up to 0.038 inch were measured.

Methods and Apparatus

All diaphragms were subjected to various static hydraulic pressures by means of dead-weight gauge testers and the resulting deflections measured. The diaphragms were clamped at their edges in an injection valve as shown in Fig. 1. Two gauge testers were used: (a) a 16,000-pound Watson-Stillman using a calibrated pressure gauge, and (b) a 750-pound Ashton using dead-weights. The deflections were measured with an L. S. Starrett universal dial test indicator graduated in thousandths of an inch. The arrangements of the apparatus are shown in Figs. 2 and 3. The valve and gauge testers were rapped lightly, and the dead weights rotated when used in order to relieve the system of slight frictional resistances.

The accuracy of the data depends upon the accuracy of the gauge testers, upon the dial test indicator and the precision with which the pressures and deflections were read. Since the

gauge testers and dial test indicator are standard test instruments, an appreciable error could probably only enter into the observed readings. This applied particularly to readings of deflections where it was necessary to interpolate between the scale divisions of the dial test indicator. The experimental points of representative curves, such as those in Figs. 5, 11, and 15, however, indicate that these observations were not greatly in error since the curves are smooth and regular and the experimental points lie very close to or upon the curves.

Diaphragms without Orifices

The load-deflection characteristics and rupture points of most single diaphragms without orifices, ranging in thickness from 0.002 inch to 0.012 inch, were determined with the Watson-Stillman gauge tester. In these tests a single diaphragm was clamped in the injection valve and hydraulic pressure applied step by step until rupture occurred. The deflections were observed at each pressure increment. Three or more complete tests were made on each diaphragm thickness and, since the observed deflections agreed to within 0.0004 inch for the same applied pressures, the data were averaged. The elastic limits of single diaphragms were determined by repeatedly loading them from zero pressure to progressively higher pressures until those deflections were reached from which the diaphragms failed to return to their initial form. This determination was made

on several diaphragms of the same thickness and the results averaged. The results of these two series of tests on diaphragms of all thicknesses are plotted in Fig. 4, the elastic limit and rupture point positions being designated on the curves.

Three items of interest may be noted in the data presented in Fig. 4. The first is the regular manner in which, for a given deflection below the elastic limit, the hydraulic pressure increases with diaphragm thickness. This is interesting since diaphragms of different thickness were punched from different stock. There was, therefore, no assurance that all the diaphragms were made from exactly the same material, that the heat treatments were the same, nor that the effect of rolling the metal to size was alike for all the thicknesses tested. These effects together with early initial yield of the metal near the clamped edge probably account for the relatively low hydraulic pressures for the 0.012 inch diaphragms. The second item is the apparent toughness of the steel. In all cases the rupture point deflections range from two to three times the elastic limit deflections. The third item is that the elastic limits are neither at nor immediately before the reversal of curvature of the curves but are approximately at the point of greatest upward curvature. This position of the yield points is explained by the fact that yield of the metal took place locally near the clamped edge of the diaphragms at lower pressures and deflections than those causing yield over the whole

diaphragm. This local yield near the clamped edge was probably caused by the compression stresses caused by clamping, and by the bending and shear stresses resulting from hydraulic pressure at this point. It was observed that many diaphragms, which had been deflected only a few thousandths inch beyond the yield point, had remained plane at all other points.

The results of a test to determine the elastic limit of a 0.004 inch diaphragm are illustrated in Fig. 5. The deformation curve shows the amount of deformation at the center of the diaphragm, resulting from any pressure and indicates that the elastic limit of this diaphragm was between pressures of 400 and 500 lb. per sq.in., or between deflections of 0.0107 and 0.012 inch. It may be noted that up to the reversal of curvature of the pressure-deflection curve, 1600 lb. per sq.in. and 0.0202 inch deflection, the deformation increment for any pressure change is less than the deflection increment. These data indicate that between the elastic limit and the reversal of curvature, the flexure of the diaphragm consisted partly of elastic deflection and partly of deformation and that, from the considerations of local yield given above, the deformation took place near the clamped edge of the diaphragm. For pressures and deflections at and immediately above the reversal of curvature the deformation increment equals the deflection increment, thus indicating that additional deflections were obtained by deformation alone and that yield took place over the

whole unsupported area of the diaphragm. At still higher pressures and deflections the deformation increment gradually became greater than the deflection increment. This may be explained by the gradually increased stiffness of the diaphragm caused by its change in shape and by the working of the metal.

Curves showing the variation of elastic limit and rupture point pressures and deflections with diaphragm thickness are plotted in Fig. 6. Since the data presented are average values from a large number of tests in which efforts were made to obtain the same test conditions for all diaphragms, it is believed that the apparent inconsistency of the rupture points is an indication of the difference in the physical characteristics of the steel. The rupture point pressures of the 0.002, 0.004, and 0.006 inch diaphragms appear to fall on one continuous curve while those of the 0.008, 0.010, and 0.012 inch diaphragms fall on another. Extending each of these curves toward the origin as shown in the figure seems to indicate that each may have resulted from different material and physical characteristics. This is quite probable since the thicker diaphragm stock was purchased $2\frac{1}{2}$ years later than the thinner stock. It may be noted that the extrapolated portions of these curves cross the axis of abscissas at a diaphragm thickness of approximately 0.001 inch, thus indicating that a diaphragm of this thickness would probably have ruptured at zero pressure had one been tested. Since the diaphragms were very firmly clamped

in the injection valve in order to approach, as nearly as possible, a fixed mounting at the rim, it is thought that these considerations indicate the effect of the clamping stresses and that a 0.001 inch diaphragm would have been ruptured solely by these forces.

The load-deflection curves of single diaphragms without orifices, tested to a point close to their respective elastic limits, are plotted in Fig. 7. These curves represent the average results of several tests on each diaphragm of the same thickness and show the characteristic hysteresis or elastic lag loops of these diaphragms for continuous testing. Though there appeared to be no regular change in the amount of the hysteresis with thickness, the thick diaphragms had more hysteresis in general than the thin ones.

The results of one series of tests on diaphragms tested in multiple to a deflection of 0.010 inch are plotted in Fig. 8. These data show the effect of individual diaphragm thickness, 0.004 inch to 0.012 inch, on the load-deflection and hysteresis characteristics for a multiple thickness of 0.060 inch. A comparison of the load-deflection characteristics of single diaphragms and diaphragms tested in multiple shows that for like deflections the loads carried by the individual diaphragms tested in multiple are approximately equal to those carried by diaphragms tested single in the case of thin diaphragms. For thick diaphragms, however, the individual loads carried are

considerably greater for diaphragms tested in multiple than for those tested singly. Analysis of the effect of individual diaphragm thickness upon the load-carrying capacities of diaphragms tested in multiple shows that at very small deflections the relation varies with the cube of the thickness as given in theoretical formulas, but for greater deflections the effect of thickness is considerably smaller, being only approximately 0.4 the theoretical value at 0.010 inch deflection. A comparison of the hysteresis characteristics of single and multiple diaphragms shows that for thin diaphragms and like deflections the hysteresis of individual diaphragms used in multiple is approximately equal to that of one diaphragm tested singly but that the hysteresis of individual diaphragms used in multiple increases rapidly with multiple thickness for thick diaphragms, reaching six times the value for one diaphragm with ten 0.012 inch diaphragms. While the hysteresis of individual diaphragms remains practically constant for any number of 0.004 inch diaphragms tested in multiple, it was found that for greater diaphragm thicknesses it increased directly with the number of diaphragms.

Several series of tests on diaphragms of all thicknesses similar to that represented by Fig. 8 were made for total thicknesses ranging from 0.012 inch to 0.180 inch and the data cross-plotted as in Fig. 9. These curves give the loads carried at 0.008 inch deflection by diaphragms of various thick-

nesses for any multiple thickness up to 0.180 inch or to a maximum pressure of 10,000 lb. per sq.in. Since a deflection of 0.008 inch is probably well within the endurance limit of these diaphragms it follows that the curves of Fig. 9 permit the safe selection of any two factors when the third is known or determine the third when the other two are fixed. For example, if in the first case the maximum working pressure is fixed at 6000 lb. per sq.in., then 0.012 inch diaphragms with a total thickness of 0.048 inch or 0.006 inch diaphragms with a total thickness of 0.096 inch may be selected. In the second case, if the multiple thickness is fixed at 0.140 inch and only 0.006 inch diaphragms are available, then the maximum permissible working pressure will be 9000 lb. per sq.in.

Since it would be necessary to take the injection valve down at various times in the course of actual engine operation and then to reassemble it with the same or other diaphragms, it was decided to determine what effect, if any, such take-down and reassembly had upon the load-deflection relationships of diaphragms used in multiple. Three diaphragm assemblies, each containing nine 0.004 inch diaphragms were, therefore, separately tested to a deflection of 0.010 inch. The maximum and minimum data from these tests are plotted in Fig. 10. The results show a maximum difference, due to variations in individual diaphragms and in the assemblies, of 2½% and one-half of 1% for the up and down readings, respectively.

Diaphragms with Orifices

The work done on diaphragms with orifices was carried out on 0.004 inch diaphragms tested singly and in multiple. The diaphragms tested in multiple consisted of nine 0.004 inch diaphragms. The orifice diameters tested were 0.015 inch, 0.060 inch, and 0.100 inch.

The problem of testing the diaphragms with orifices was different from that of the diaphragms without orifices in that the direct retention of the hydraulic pressures was impossible. Also, the deflections of the diaphragms without orifices had been measured at their centers, while it was necessary with the diaphragms with orifices to measure the deflections at the orifice edge or at some fixed radius from the center.

Two methods of maintaining pressures and two methods of measuring deflections were investigated. The first method used to maintain the hydraulic pressures was to cover the hole in the diaphragms with one solid diaphragm and then to make corrections for the solid diaphragm so as to obtain the load-deflection relationships for the diaphragms with orifices. The effect of the single diaphragm without the orifice was approximately determined by testing 10 diaphragms without orifices and subtracting from the results those obtained by testing 9 diaphragms without orifices. The second method investigated was to retain the pressures by means of a wide angle

conical pointed stem progressively advanced into the orifice. The injection valve assembly with this stem is shown in Fig. 1. The test was conducted by screwing the stem in until the conical point seated in the orifice and produced a definite deflection as indicated by the dial test indicator. Hydraulic pressures were then applied until a rapid flow of the oil used in the gauge tester through the orifice took place. Under these conditions the effect of the central loading imposed by the stem was eliminated, the diaphragm being loaded only by hydraulic pressure. Readings of both the pressure and deflection were taken at this point. By screwing the stem in by increments of 0.001 inch and observing the flow pressures and deflections data were obtained over a range equal to that for the diaphragms without orifices. Since this method of loading the diaphragms with orifices simulated the conditions of actual operation in an injection valve more closely than the first method it was adopted for these tests.

The first method used to measure the deflections of diaphragms with orifices employed a knife edge on the indicator arm. This was adjusted so as to bring the knife edge across a diameter of the orifice. Hence it measured the deflection produced at the orifice edge. The second method employed a straddle point on the indicator arm. This had two points which contacted with the diaphragm on either side of the orifice, its position being adjusted so as to measure the deflec-

tions produced on a circle concentric with the orifice and 5/32 inch in diameter. This method was adopted for these tests since all deflections were thus obtained at the same distance from the support circle.

In order to show the relationship between deflections at a circle 5/32 inch diameter as obtained with the straddle point and those at the diaphragm center as obtained with the cone point, tests were made with each point on the same 0.004 inch diaphragms without orifices to a pressure of 400 lb. per sq.in. The results are plotted in Fig. 11, where also the cone and straddle points, as attached for these tests to the ball at the end of the indicator arm, are illustrated. The curves show lesser deflections for the straddle point at all pressures which are, within the range tested, approximately 84% of the deflections obtained with the cone point.

The work done on single diaphragms with orifices is presented in Fig. 12, and that on diaphragms with orifices tested in multiple in Fig. 13. In all cases the diaphragms having large orifices required higher pressures, for the same deflections, than did those having small orifices. This may be explained by the fact that the hydraulic pressures producing the deflections in diaphragms with large orifices not only had less unsupported area to stress, thus decreasing the total supported load, but also acted on a shorter average lever arm from the support circle, thus making them less effective.

While there is no doubt that the presence of the orifices weakened the diaphragms and produced high local stresses at the orifice edges, there were no evidences of yield or incipient rupture noted in any of the tests. The effect of the diameter of the orifice upon the pressure relationship at deflections of 0.004 and 0.006 inch for single and multiple diaphragms are shown in the inserts in Figs. 12 and 13, respectively.

Comparison of Experimental Data with Theoretical Data

Curves plotted from the experimental data are compared with curves plotted from the usual formulas for the deflections of uniformly loaded circular plates rigidly clamped at their edges in Fig. 14. Several characteristic differences between the curves obtained from the experimental data and the formulas may be noted:

First, the experimental curves are parabolic in form while the theoretical curves are straight lines.

Second, the loads carried by diaphragms 0.008 inch thick or less, are much greater in general in the experimental curves than in the theoretical curves. This pressure difference increases rapidly with increase in deflection and decrease in diaphragm thickness.

Third, the variation of the experimental deflection with diaphragm thickness is not inversely as the cube of the thickness as is the case for the theoretical curves.

An analysis of the various derivations of the theoretical formulas shows that assumptions have been made which employ approximate relationships and eliminate certain variables from the formulas altogether. Some of the assumptions are that the deflections will be small and that angles of inclination will be, therefore, equal to their sines or tangents, that the middle layer in the plate will be a neutral layer having neither stress nor strain and, that all elements that are straight and perpendicular to the neutral plane or axis of the diaphragm before flexure will remain straight and perpendicular to the neutral axis after flexure; that a ring of these elements concentric with the center of the diaphragm will, if produced, meet in a point on an axis perpendicular to and through the cneter of the diaphragm, thus forming a cone of produced elements and, finally, that since the angle which these elements will make with the perpendicular axis will be small the cone thus formed may, therefore, be considered a right cylinder. Compressive stresses caused by loads on and perpendicular to the plate, shear stresses caused by strains and approximations beyond the first order are neglected in the derivations.

It is found that these assumptions and omissions make the formulas inapplicable to the diaphragms as tested at comparatively large deflections in this research. The approximately spherical surface of a thin diaphragm having an unsupported diameter of 0.4 inch stressed to a deflection equal to 4% of

its unsupported diameter, i.e., 0.016 inch, has a radius of about 1 inch. The maximum angle which the produced elements will make with the vertical axis through the center of the diaphragm, will be about 10 degrees. This angle will vary greatly depending upon the deflection, the location of the reversal of curvature, and the radius of the circle from which the elements are produced. As a diaphragm is deflected, the apex of the cone of produced element moves in along the perpendicular axis from infinity to a point relatively close to the diaphragm. Since the deflections obtained in this research are not small, these variables together with compressive and shear stresses and the rapidly changing shape of the diaphragm introduce effects which make the form of the load-deflection curve materially different from that derived in the formulas.

The form of the load-deflection curve of rigidly clamped diaphragms is also influenced by the ratio of diaphragm thickness to deflection. If a diaphragm 0.002 inch thick is deflected 0.016 inch, the whole of its inner surface and nearly all of its outer surface is in tension. The small part that is in compression lies in the outer surface of the diaphragm between the clamped edge and the reversal of curvature. The stresses in the diaphragm are therefore largely analogous to those in a portion of a hollow sphere of 0.002 inch wall thickness and diameter of about 2 inches, the inner fibers being stressed in tension exactly like the outer fibers, though in somewhat less

degree. The relations, using the above as a basis, between the loads and the resulting deflections in rigidly clamped diaphragms having deflections equal to or greater than their thickness can be shown to be of the form, $P = Cd^2$, in which

P = unit pressure acting on the diaphragm,

C = constant, and

d = deflection of diaphragm at its center.

Fig. 15 illustrates the close agreement obtained between an experimental load-deflection curve and the parabola,

$P = 3,711,000\ d^2$. It may be noted that the two curves coincide, within the limits of experimental accuracy, up to the elastic limit. The point at which the experimental curve deviates from the parabola, that is, the elastic limit of this diaphragm, is given by the point of initial deformation as indicated in the deformation curve, by the point at which the experimental value of C deviates from a constant and, in the case of this diaphragm, approximately by the reversal of curvature of the load-deflection curve.

Specifications of the Steel

The steel from which the diaphragms were made was purchased competitively in the open market under the specification "Ultra Superior Swedish blue tempered spring steel." The steel has a deep purple temper color with streaks and small areas of light purple, brown purple and light blue, indicating an aver-

age drawing temperature of approximately 550°F. The effect of rolling the stock to size is clearly shown in the "rolled out" or lined appearance of the temper colors. The fact that nearly all the fractures obtained in the rupture point tests were with the direction of rolling, indicates that the structure of the metal was probably considerably distorted and weakened.

The following chemical and physical analyses, with the exception of the modulus of elasticity of the steel, were reported by the Bureau of Standards:

Chemical Analysis -

Carbon	1.29%	Sulphur	0.015%
Manganese	0.27%	Silicon	0.12%
Phosphorus	0.019%	Iron	remainder

Physical Tests -

Ultimate strength, pounds per square-inch, average for all thicknesses,	275,000
Elongation, per cent in 2 inches, average for all thicknesses,	2.8
Modulus of elasticity, pounds per square-inch, 0.012 inch thickness only,	28,200,000.

General Results

Analysis of the test results of single diaphragms shows that up to the elastic limit the deflection varied directly with the square root of the unit pressure times a constant and

inversely as a function of the diaphragm thickness, which for very small deflections is the cube but which decreases rapidly for greater deflections, reaching approximately the 0.8 power of the thickness at a deflection of 0.010 inch.

The elastic limit deflections vary from approximately 2.75 per cent to 3.50 per cent of the unsupported diameter for diaphragms having ratios of unsupported diameter to thickness of from 33 to 200, respectively. The rupture point deflections average 8 per cent of the unsupported diameter.

The load capacities of multiple diaphragms increased almost directly with the total thickness and, for equal total thicknesses, with a variable function of the individual diaphragm thickness. The load capacities of orifice diaphragms increased considerably with increase in orifice diameter.

The hysteresis or elastic lag characteristics of single diaphragms increased in general with diaphragm thickness. For composite diaphragms the hysteresis increased with diaphragm thickness and remained practically constant with various multiple thicknesses for thin diaphragms but increased rapidly with multiple thickness for thick diaphragms.

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Deformation was found to be of two kinds: that which took place at or very close to the clamped edge of the diaphragm caused by local bending and clamping strains and that which took place throughout the whole diaphragm. The initial deformation at the clamped edge occurred, to some extent, very

early in the tests of the medium and thick diaphragms so that the true relationships of these diaphragms were somewhat masked.

Analysis of the derivations of the usual formulas for the deflections of rigidly clamped circular plates and comparison with the experimental data, show that the formulas are inapplicable to the range of test conditions of this research.

Conclusion

The results of this research show that small diameter steel diaphragms used in multiple have load capacities and deflections that make them suitable for use as the flexible member in automatic fuel injection valves.

References

1. Joachim, W. F. : An Investigation of the Coefficient of Discharge of the Flow of Liquids through Small Round Orifices. N.A.C.A. Technical Report No. 224 - 1925.

2. Hersey, M. D. : Diaphragms for Aeronautic Instruments. N.A.C.A. Technical Report No. 165 - 1923.

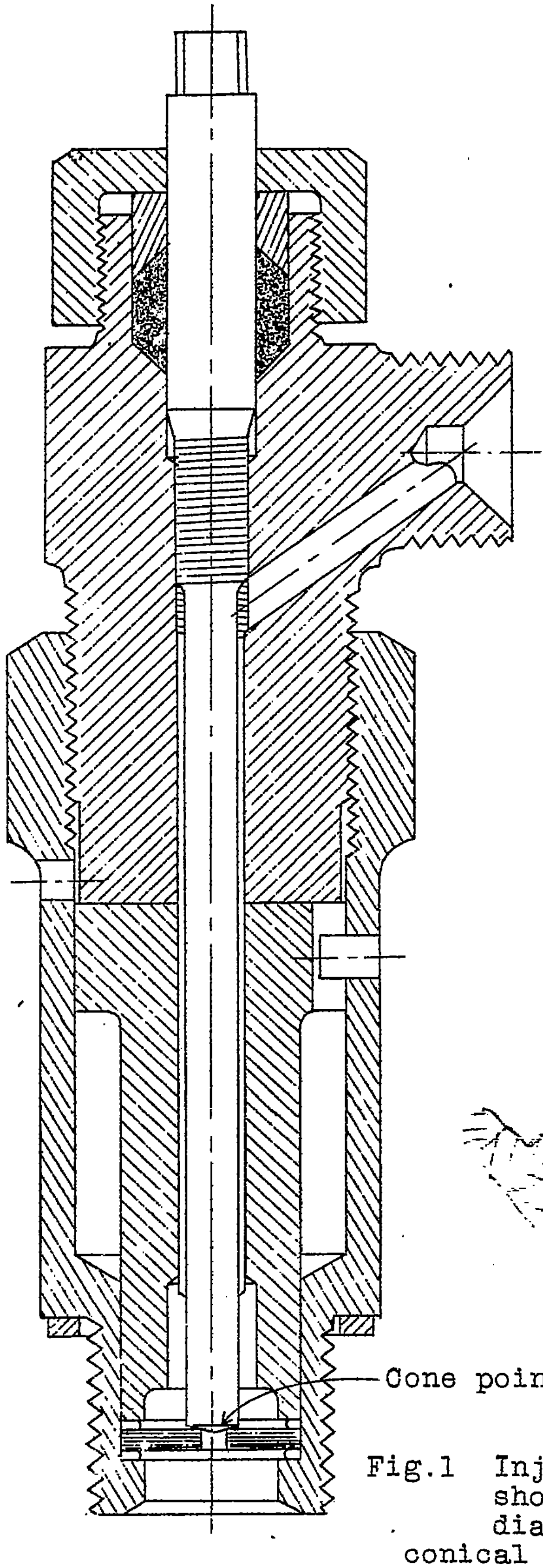

Fig.1 Injection valve showing orifice diaphragms and conical pointed stem.

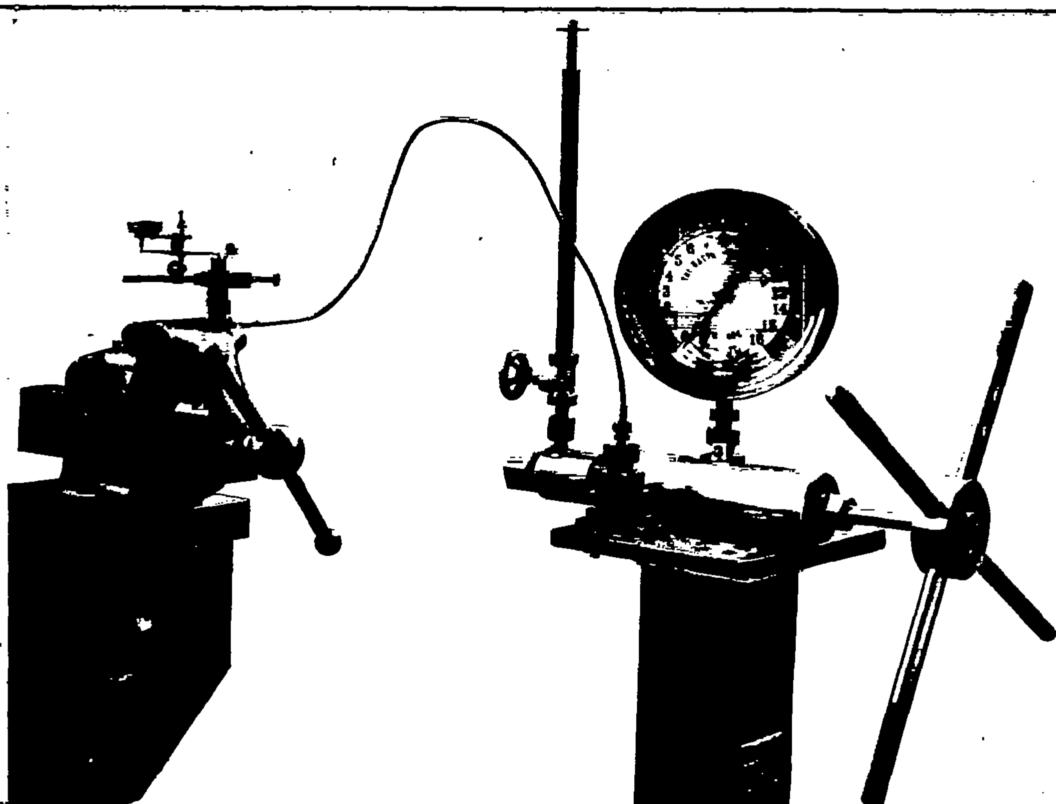

Fig. 2 Diaphragm test apparatus using Watson-Stillman gauge tester and 16000 pound test gauge.
1. L.S.Starrett dial test indicator.
2. Injection valve holding diaphragms under test.
3. Watson-Stillman gauge tester and gauge.

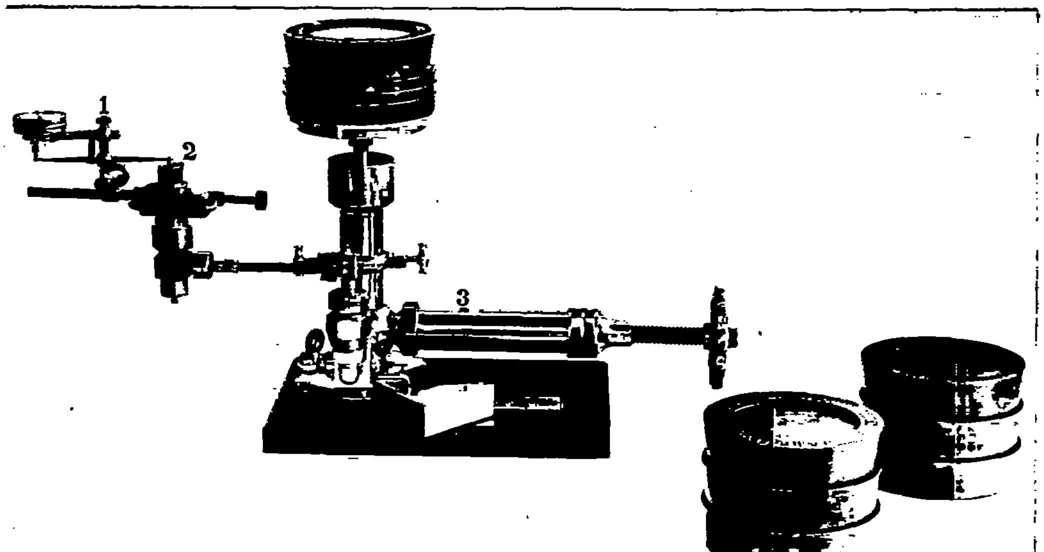

Fig. 3 Diaphragm test apparatus using Ashton dead-weight gauge tester
1. L.S.Starrett dial test indicator.
2. Injection valve holding diaphragms under test.
3. Ashton dead weight gauge tester.

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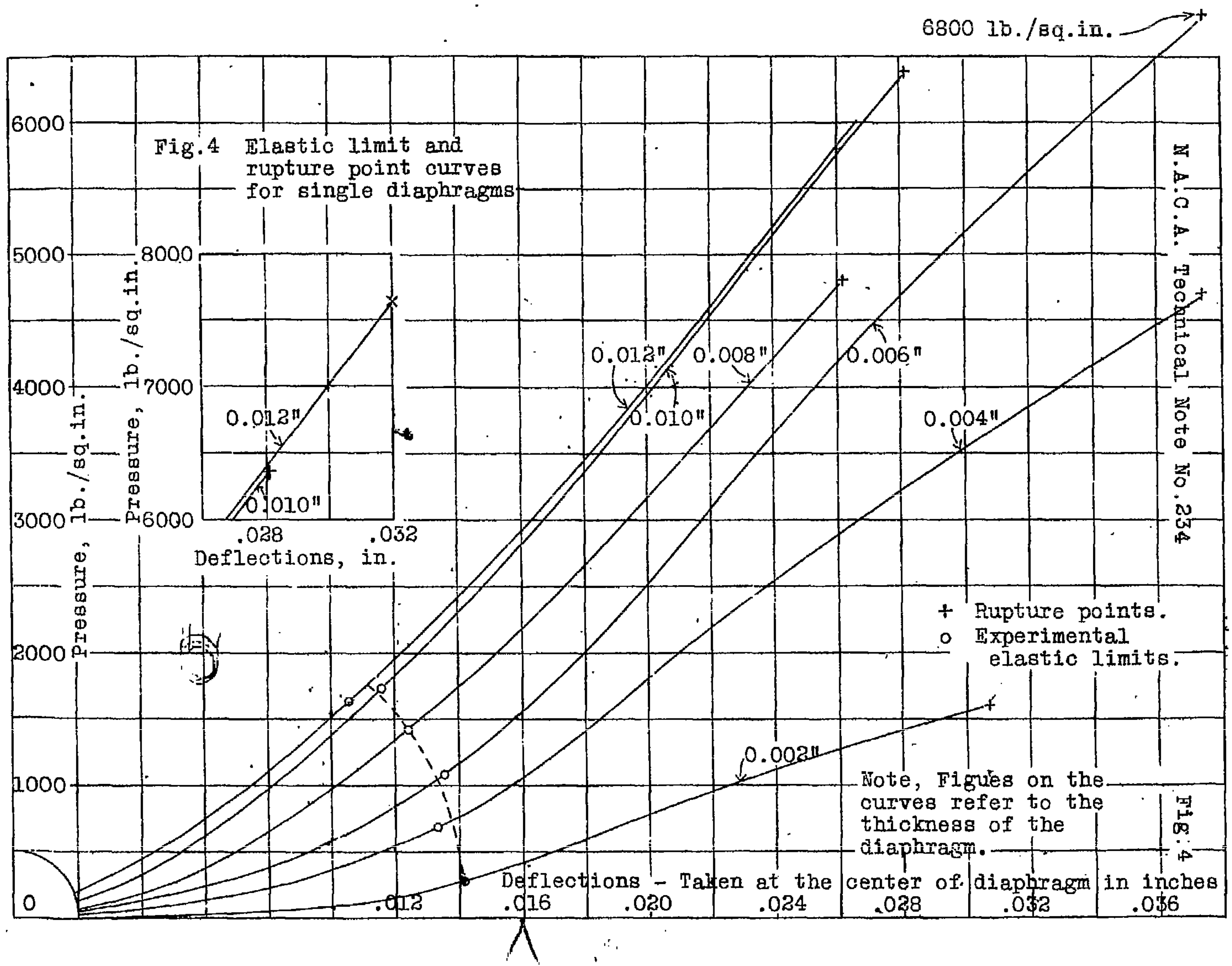

6800 lb./sq.in.
6000
5000
4000
3000
2000
1000
0
Pressure, lb./sq.in.
Fig.4 Elastic limit and rupture point curves for single diaphragms
8000
7000
6000
Pressure, lb./sq.in.
0.012"
0.010"
.028
.032
Deflections, in.
0.012"
0.008"
0.006"
0.010"
0.004"
0.002"
N.A.C.A. Technical Note No.234
+ Rupture points.
o Experimental elastic limits.
Note, Figues on the curves refer to the thickness of the diaphragm.
Deflections - Taken at the center of diaphragm in inches
.012
.016
.020
.024
.028
.032
.036
Fig.4

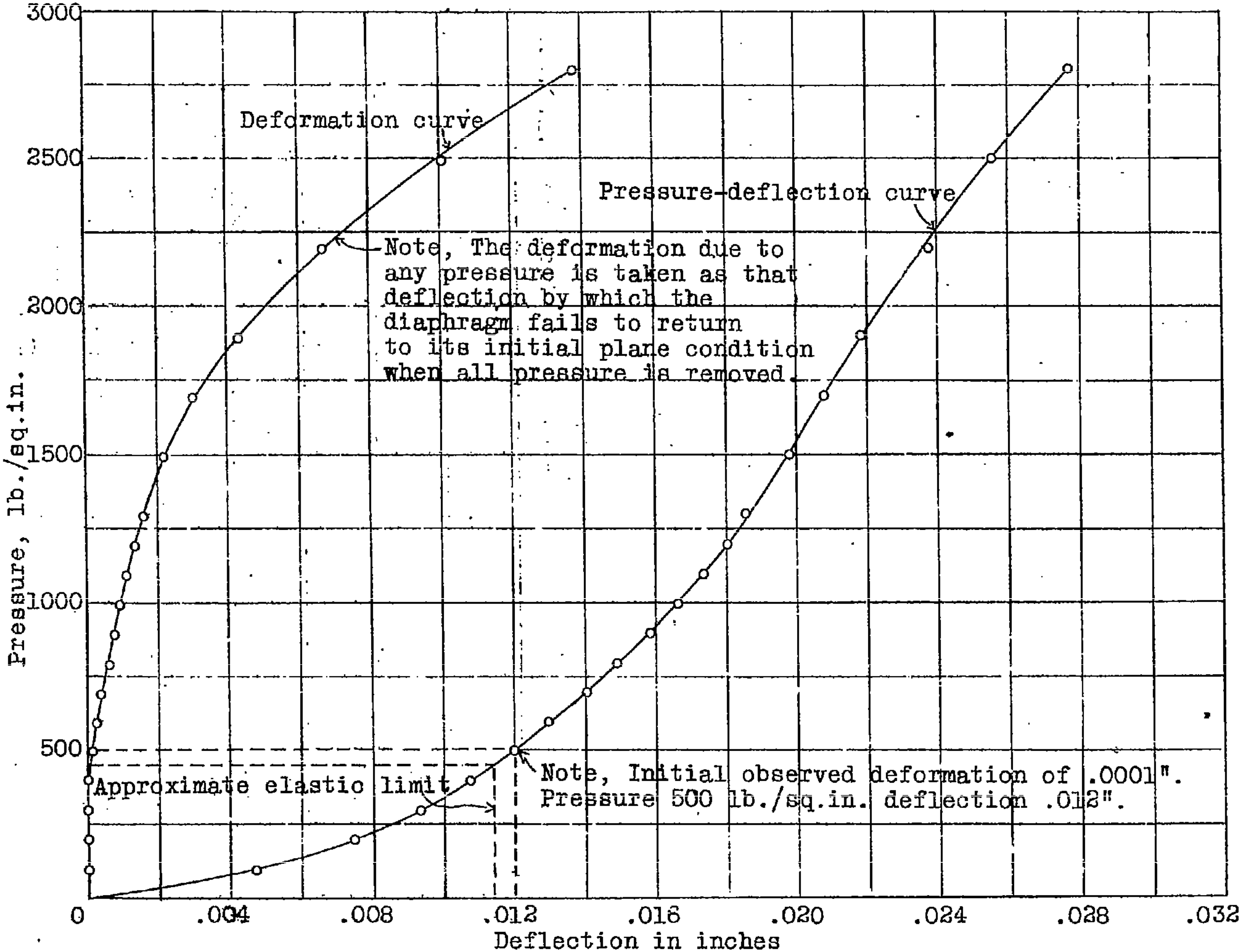

Fig.5 Pressure-deflection & deformation curves indicating the elastic limit of a .004" diaphragm.

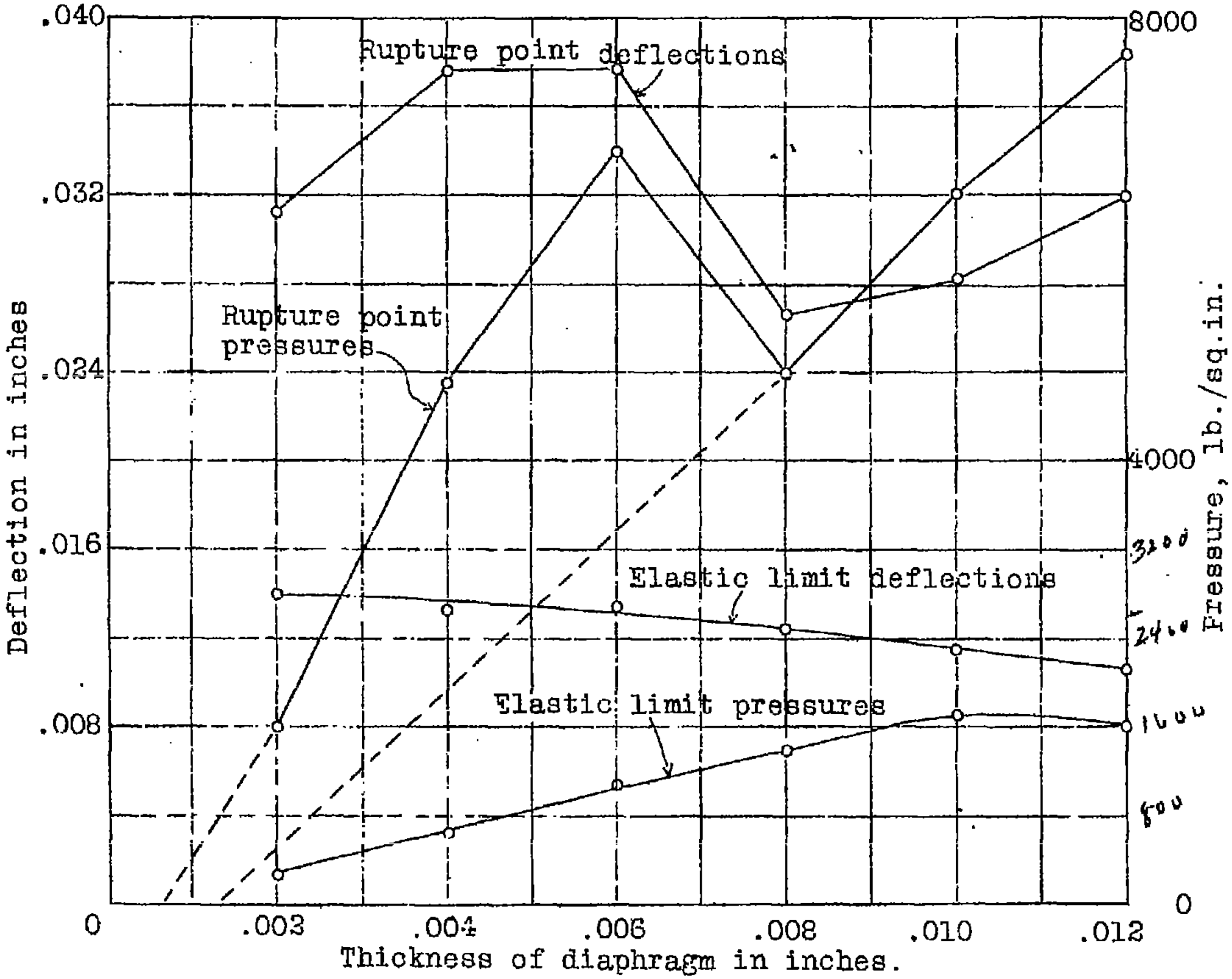

Fig.6 Elastic limit and rupture point variation with change of diaphragm thickness.

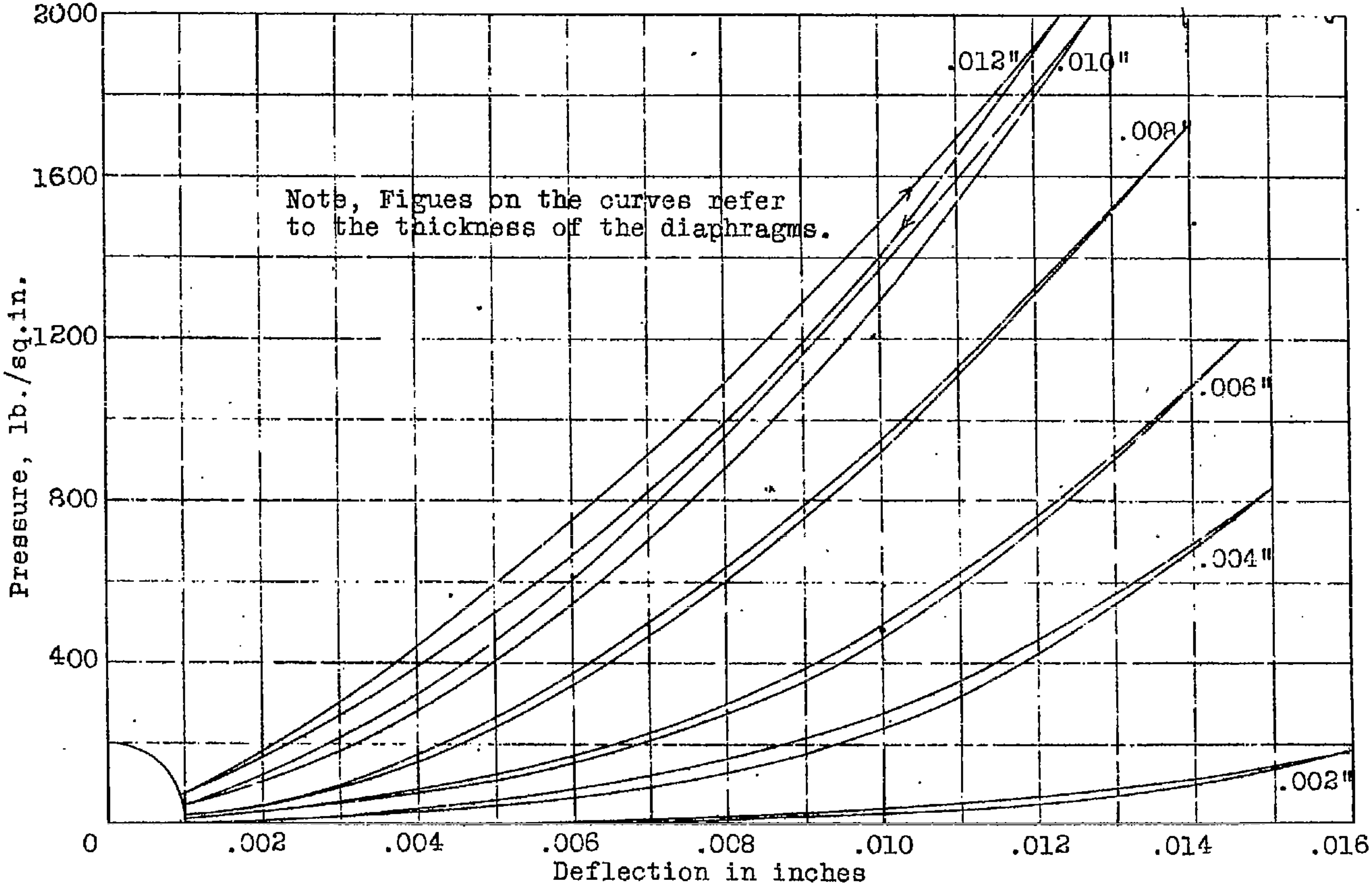

Fig.7 Pressure-deflection curves of single diaphragms.

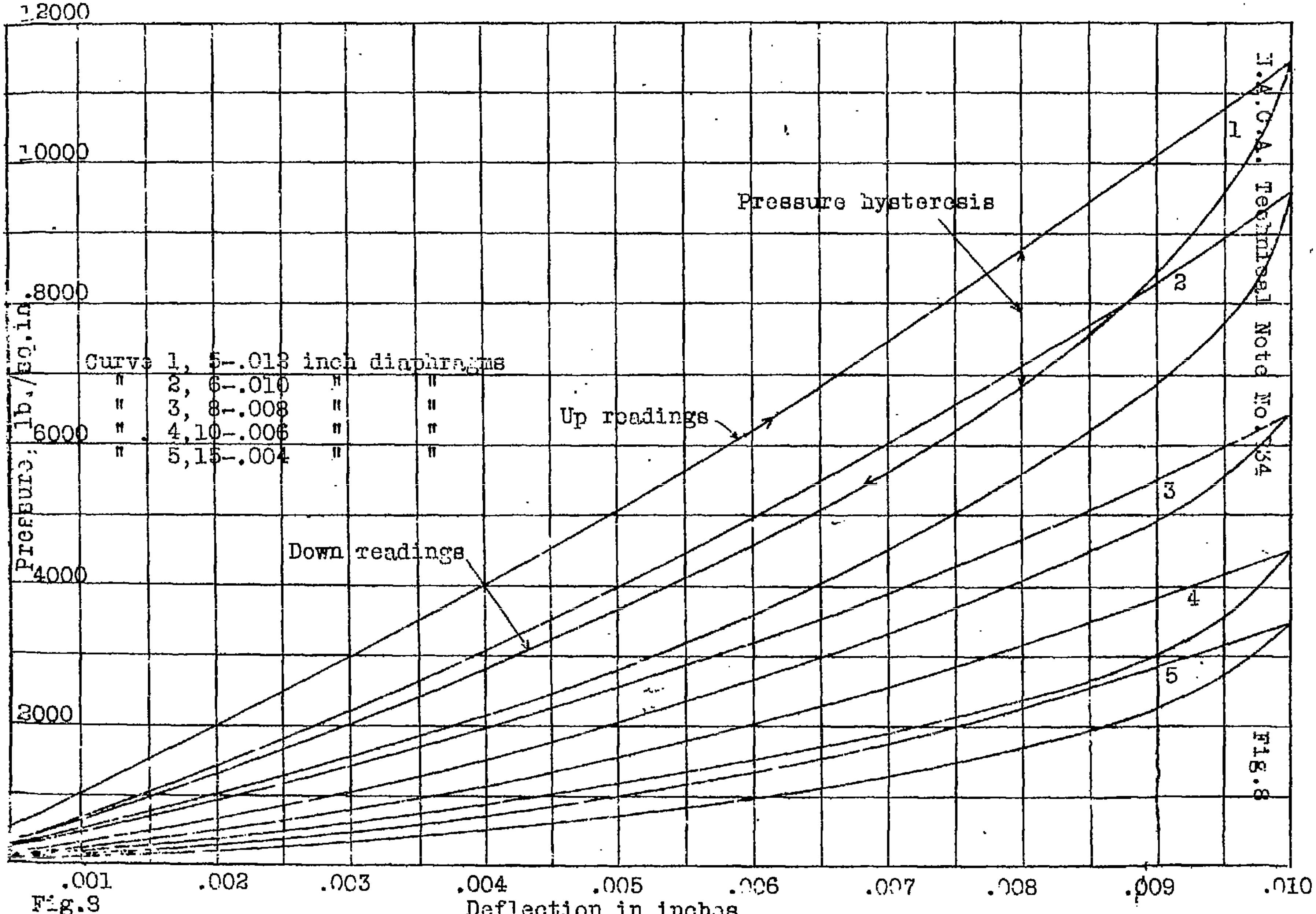

Fig.8
Pressure-deflection & hysteresis curves of multiple diaphragms. Multiple thickness .060 inch.

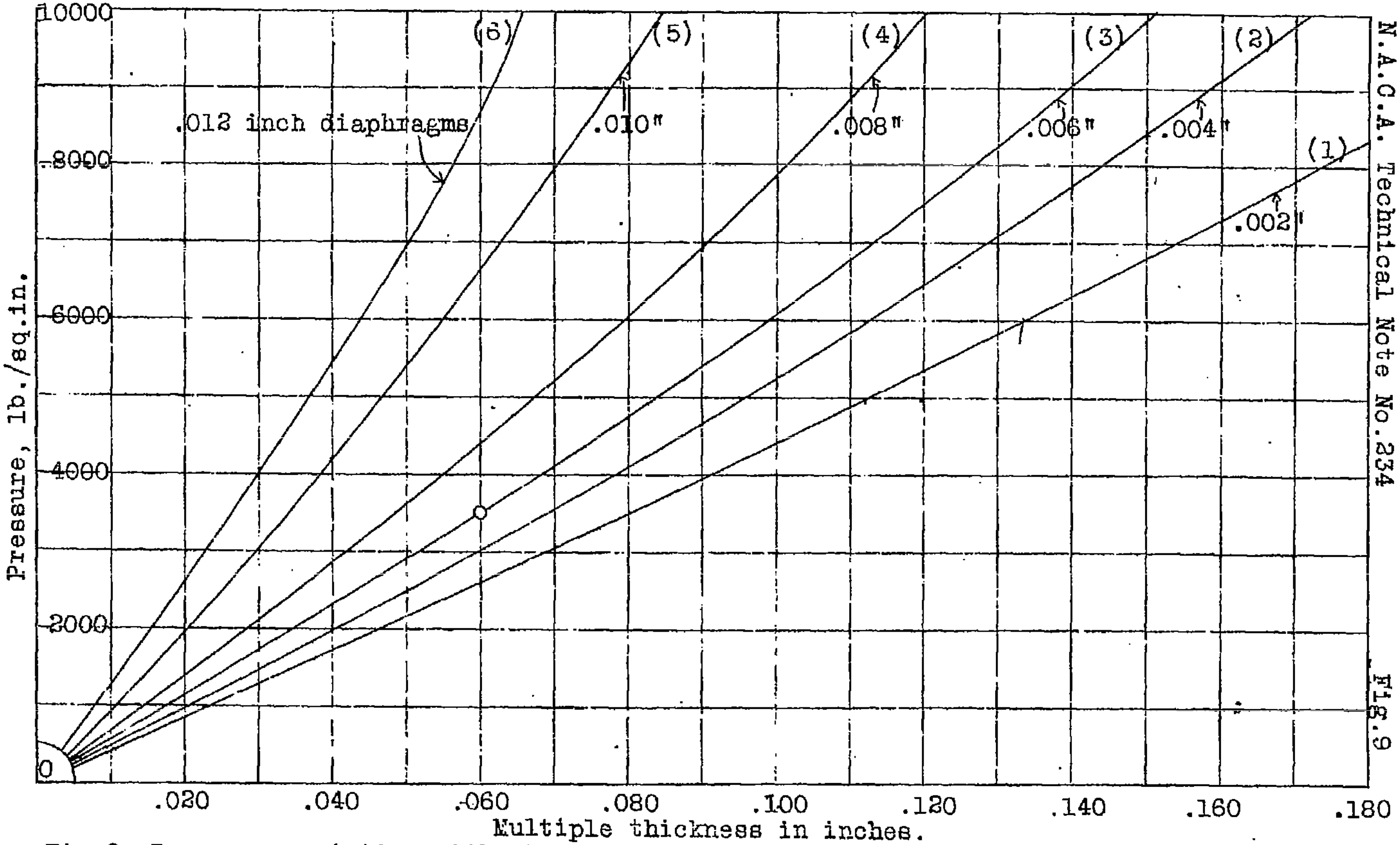

Fig.9 Pressure variation with change of multiple thickness taken at a deflection of 0.008 inch for all diaphragms.

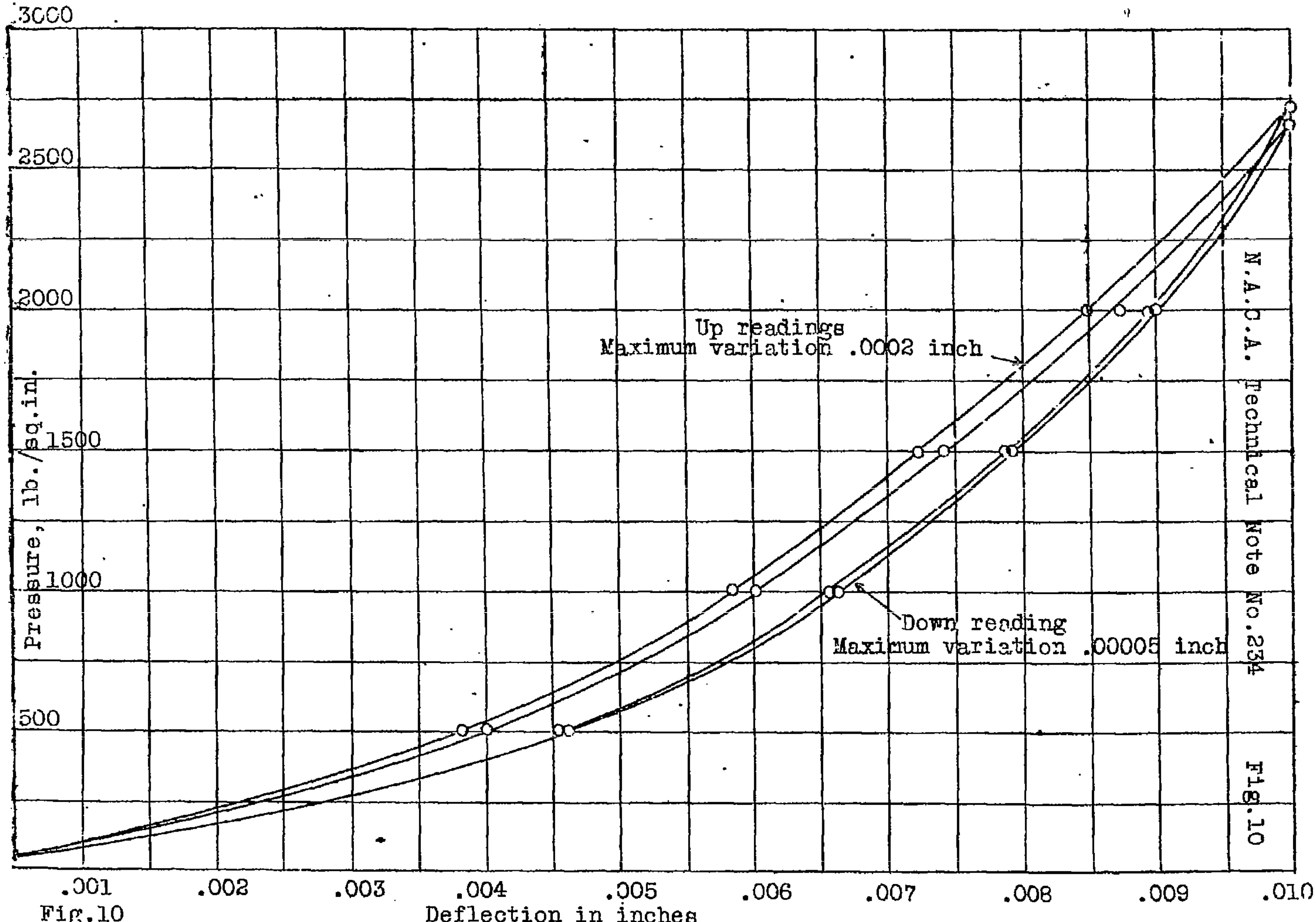

Fig.10
Maximum variation observed between separate tests on similar sets of multiple diaphragms, each composed of nine diaphragms 0.004 inch thick.

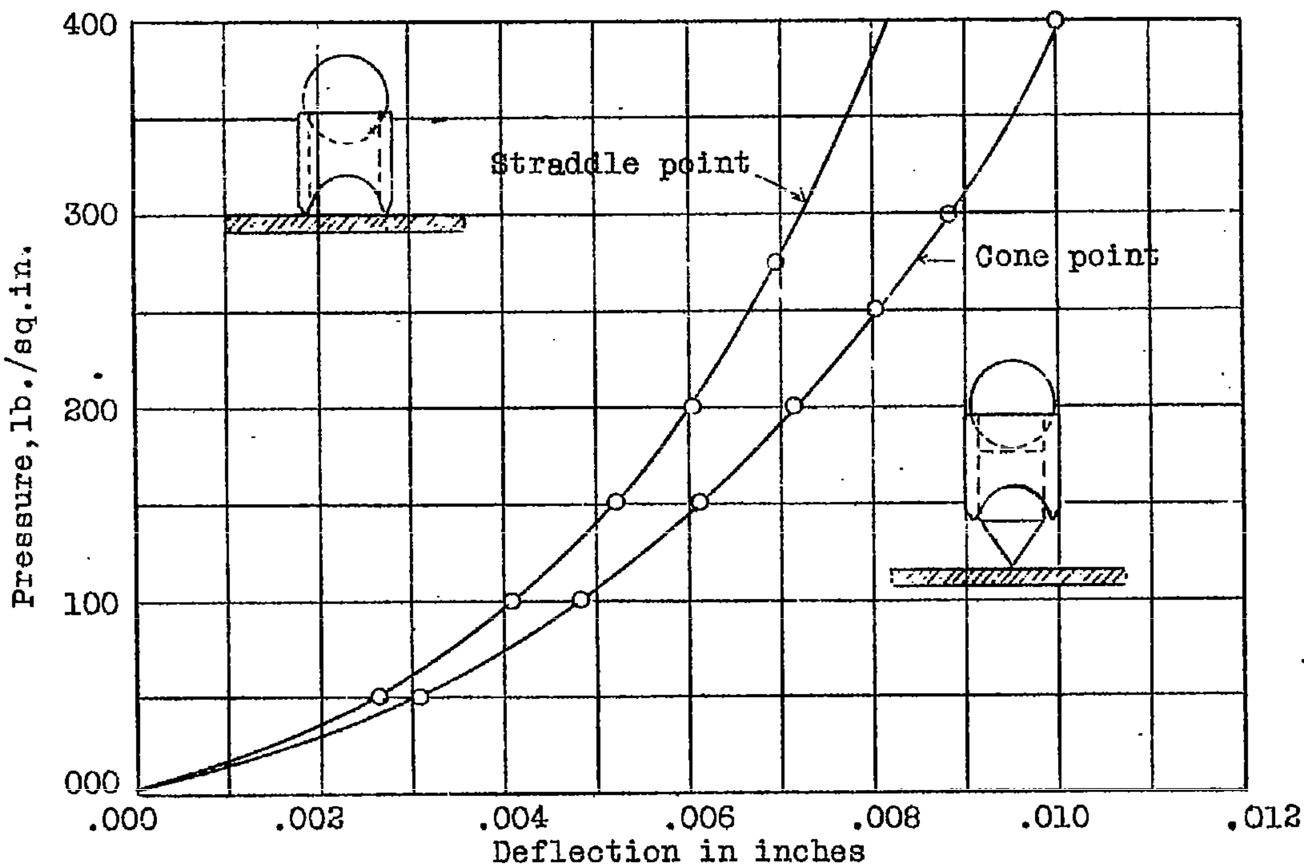

Fig.11 Comparison of the deflections of a 0.004 inch diaphragm as obtained with the cone and straddle points.

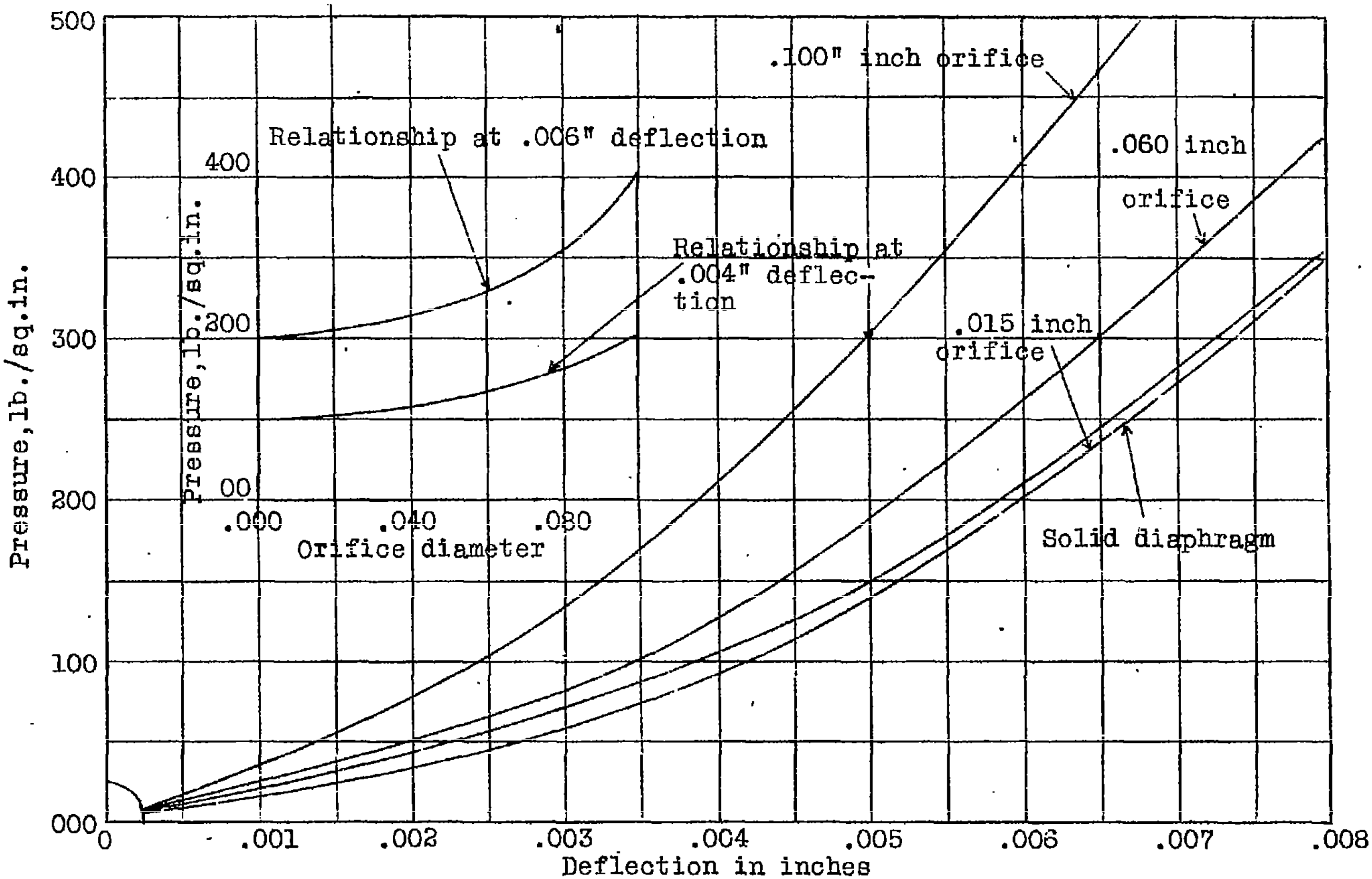

Fig.12 Effect of orifice diameter on the pressure-deflection characteristics of single 0.004 inch diaphragms. Deflections measured with straddle point.

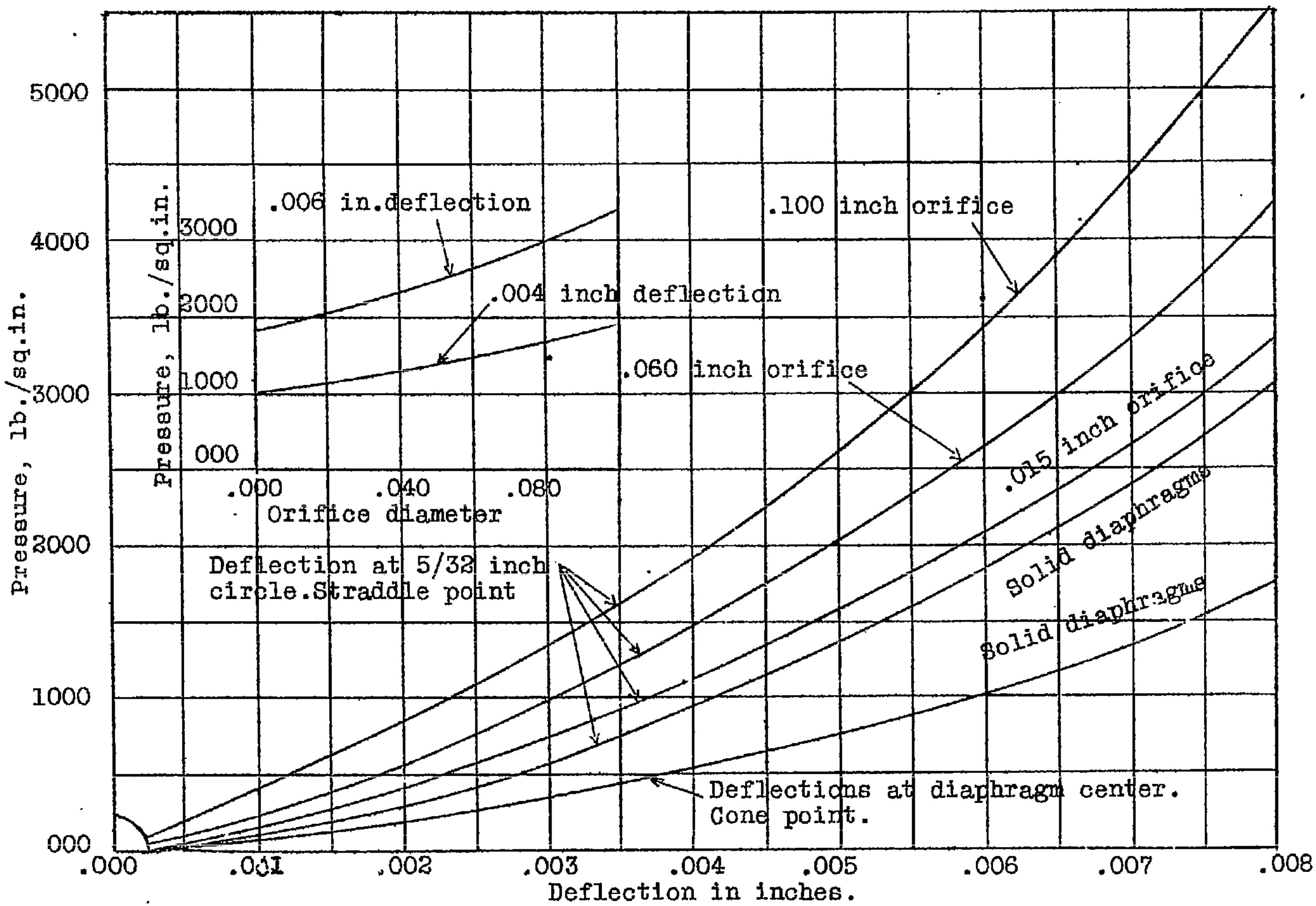

Fig.13 Effect of orifice diameter on the pressure-deflection characteristics of multiple diaphragms each composed of nine 0.004 inch diaphragms.

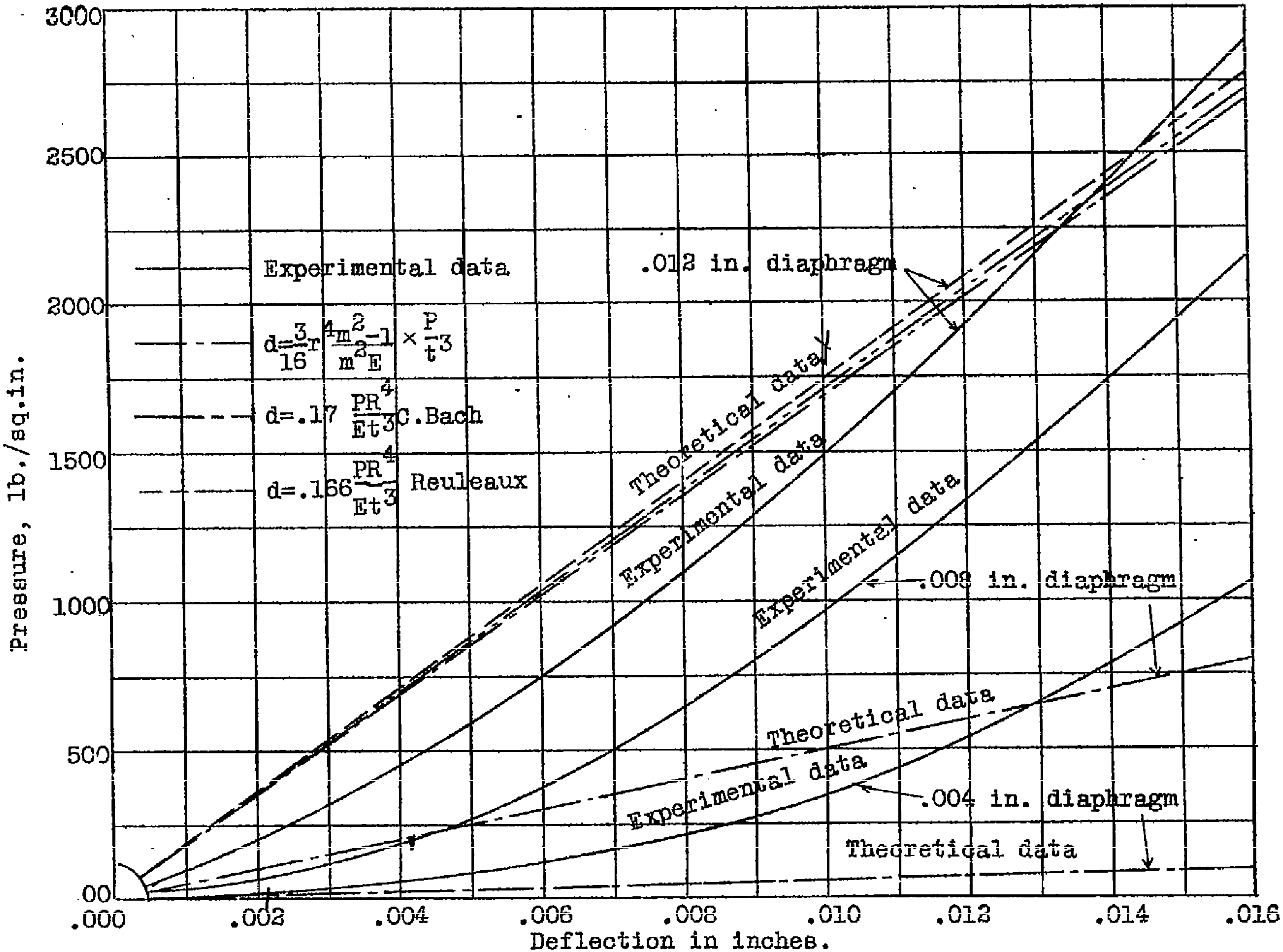

Fig.14 Comparison of theoretical with experimental data.

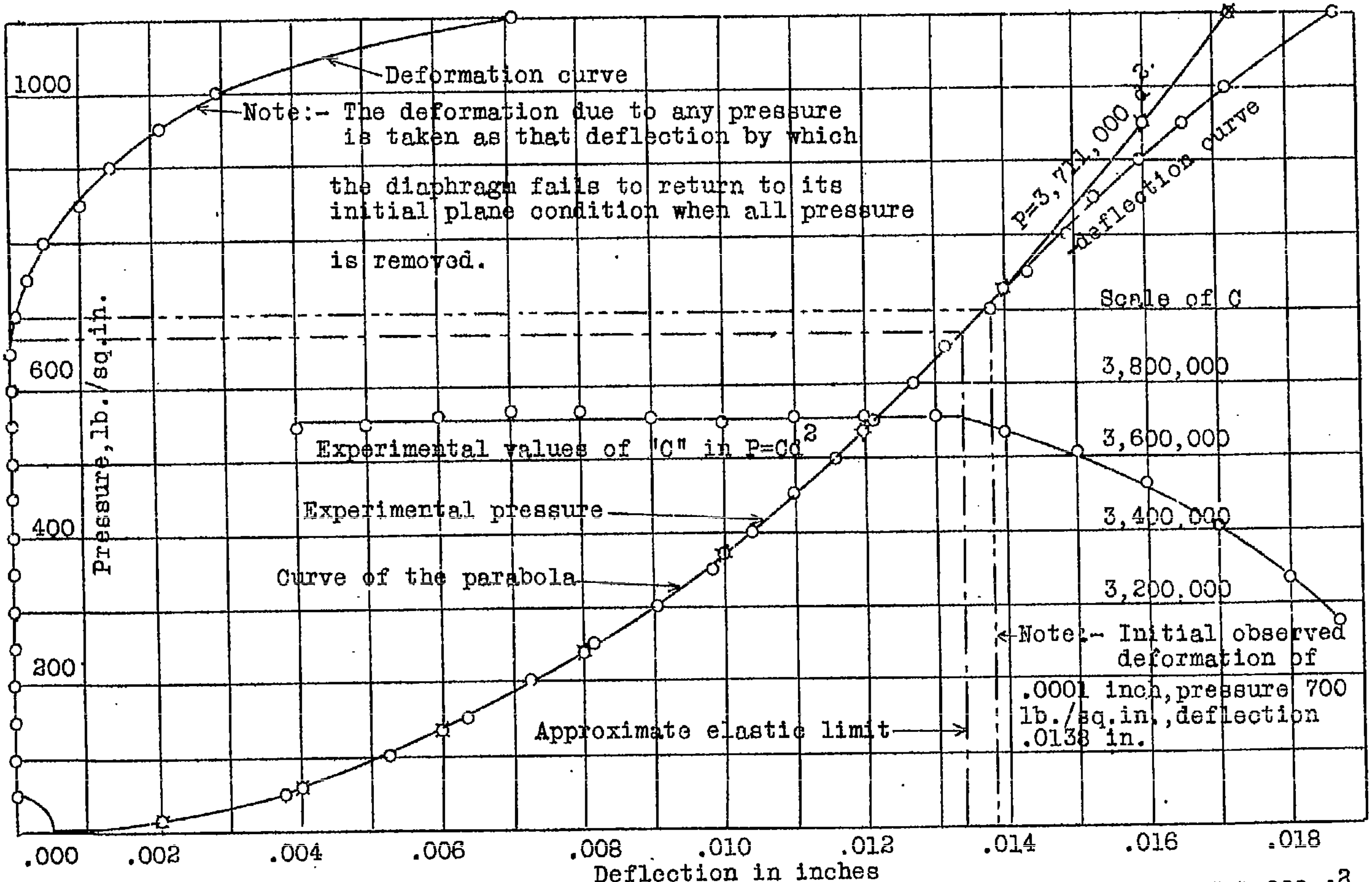

Fig.15 Comparison of experimental data for a thin diaphragm with the parabola $P=3,711,000\ d^2$